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Development of Flood Space Monitoring in Kazakhstan

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1. Introduction

From the moment of appearance of the first systems of remote sensing of the Earth, allowing to carry out survey in a real time mode, one of the main directions of their use is the operative control of various emergency situations, first of all fires and high waters. At the same time the general principles and methods of space monitoring of high waters and flooding have been formulated (Barton & Bathols, 1989). Now this direction still intensively develops in the various countries.

In Kazakhstan such large flooding which are characteristic for the Siberian rivers and modern Europe were observed seldom. Therefore real conditions for development of system of space monitoring of flooding have appeared after installation at Space Research Institute (now it was a part of National Center of Space Research and Technologies) in 2001 reception station of the Russian firm SCANEX providing reception of Terra MODIS data (the resolution 250 m) in a real time mode. Since then this system actively developed in Kazakhstan (Spivak et al., 2004, 2005; Arkhipkin et al., 2007; Arkhipkin & Sagatdinova, 2008). It should provide the operative observation of republic territory, detection and mapping the real and potential centers of flooding of natural and technogenic character.

The brief description of technology of work of flood space monitoring system and the most important results is presented below.

2. Water system of Kazakhstan

Kazakhstan is located in the centre of the Eurasians continent and enters into ten greatest on the area of the countries of the world. Its area is 2,7 million square kilometers. In too time in such big territory there lives the small population (only 16 million people).

Despite the location and arid climate, Kazakhstan has considerable number of various water objects /figure 1/. Largest of them well-known all over the world, thanks to the environmental problems which make essential impact on considerable territories of the Eurasians continent. There are Caspian Sea and Aral Sea. We have also many lakes (more than 35 000), including such large as Balkhash, and many (more than 3 000) artificial water objects (water basins and ponds).

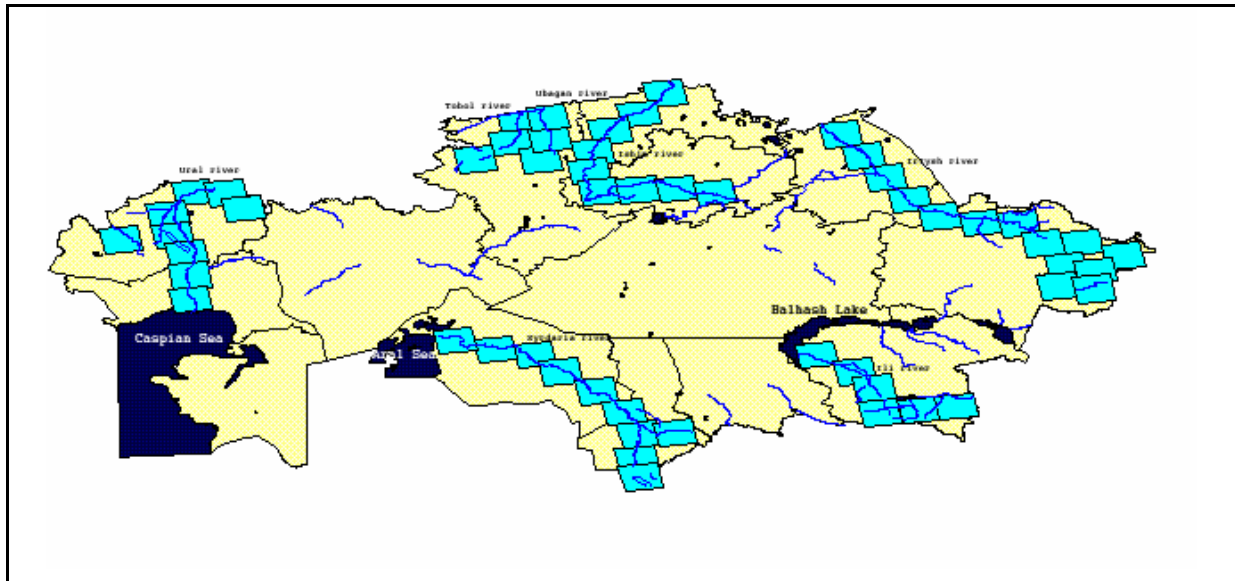


Fig. 1. Main regions of Kazakhstan with high risk of flooding by spring water and flood

In Kazakhstan there is a great number of the rivers. Mainly they have the average and small size. The largest rivers are Irtysh, Ural, Tobol, Ishim, Syr daria and Ili. During spring thawing snow the volume of flow of these rivers sharply increases, sometimes more than 1000 times. They can overflow banks and flood large territories. The maximal hoisting of water recorded in the river Ural was in 1942, when the water was pushed up on 10-11 m above the normal level.

Let's notice that all large river systems of Kazakhstan have transboundary character. Therefore their problems become the general for the several countries: Russia, China, Uzbekistan, the Kyrgyz Republic. In the past years we observed a very interesting situation in the region of the Syr daria River. On the one hand, we observed big shortage of water in the Aral Sea, and on the other hand - during the winter-spring period in middle stream of the Syr daria we observed its overabundance. Such situations arose because of inconsistency of questions of water use between Kazakhstan, Uzbekistan and Kyrgyzstan.

3. Main tasks of Space monitoring of a water objects of Kazakhstan

At the present time it is more efficient to control water objects on such big territory as Kazakhstan using space monitoring. Each class of water objects has its own tasks.

Environmental problems of the Caspian region are caused by rapid development of oil-extracting branch around Northern Caspian Sea and sea level rising. Therefore the main tasks of space monitoring of water surface of the Caspian Sea are:

- Operative detection and monitoring of migration of oil spills on the water surface during flooding of oil derrick during the period of high water on the Caspian Sea and movement of tankers on its water area of Caspian Sea;
- Monitoring of oil derrick in the Caspian shelf zone,
- Control of ice conditions in this region.

A number of organizations of Kazakhstan, including SRI take part in the solution of these problems. Base for the solution of these problems is RADARSAT (modes from Fine to ScanSAR Wide) and IRS data.

Environmental problems of the Aral region are caused by sharp and fast reduction of the water surface. As a result of it the surface of the dried up bottom of Aral Sea which is a source of the powerful dust storms extending on considerable distances increases also quickly. In this case the primary tasks of space monitoring are:

- Monitoring of a water surface of the Aral Sea,
- Detection and monitoring of dynamics of development of dusty storms,
- Detection and analysis of the dusty storms centers,
- Modeling of occurrence and dynamics of development of dusty storms.

Many organizations both in Kazakhstan and in other countries participate in the solution of these problems. SRI also takes part in it, including participation in the international grants (for example, CALTER).

The main task of Space monitoring of water objects is mapping of flooding zones during passage of freshet waters and flooding. Floods are a considerable menace for the part of the population of Kazakhstan living not only on the banks of large rivers, such as the Irtish, Ural, Tobol, Ishim, Syrdaria, but also on the banks of small rivers. In recent years the situation in the Kyzyl-Orda oblast has become especially aggravated.

At the previous and initial stage of high water passage we carried out mapping of destruction of the snow cover on the territory of the region, and recently we made mapping of destruction of an ice cover on large water reservoirs and lakes. In view of worsening of flood situation in the middle stream of the Syrdaria during the winter-spring period in the past years, the space monitoring of dynamics of filling of the Chardara reservoir was formulated as a special task. The development of flood situation in this region strongly depends on the Chardara reservoir. Space monitoring of dynamics of filling of the water surface of the Chardara reservoir is divided into two tasks. The first is satellite surveying of the current situation, and the second is comparison of this situation with the dynamics of the situation development in the past years.

4. Space monitoring of snow cover destruction

As it was mentioned above, the first stage of space monitoring of high waters is space monitoring of the snow cover destruction. Special programs are devised to automatize the process of process of mapping of snow, ice and water covers, which allows to carry out, in the automated mode, the procedure of transformation to a required projection, cutting of necessary territory, calculation of various indexes (NDSI, NDVI, VI) and classification of images in MODIS data. Simultaneously masks of a cloudy cover and maps of temperature of of the earth surface are formed. Masks of a cloudy cover specify territories on which the condition of an earth surface is not defined. The maps of temperatures combined with masks of a snow or ice cover, specify zones of active thawing on which the temperature is more 0°C (melt snow).

By the results of space monitoring of destruction of a snow cover, the special maps indicative of the current condition of a snow cover /figure 2/, dynamics and calendar terms of destruction a snow cover are constructed /figure 3/. This information is very interesting for the forecast of a freshet situation. It allows to estimate terms of the beginning of thawing of a snow cover (early, normal, late), and also its rate (fast, normal, slow thawing).

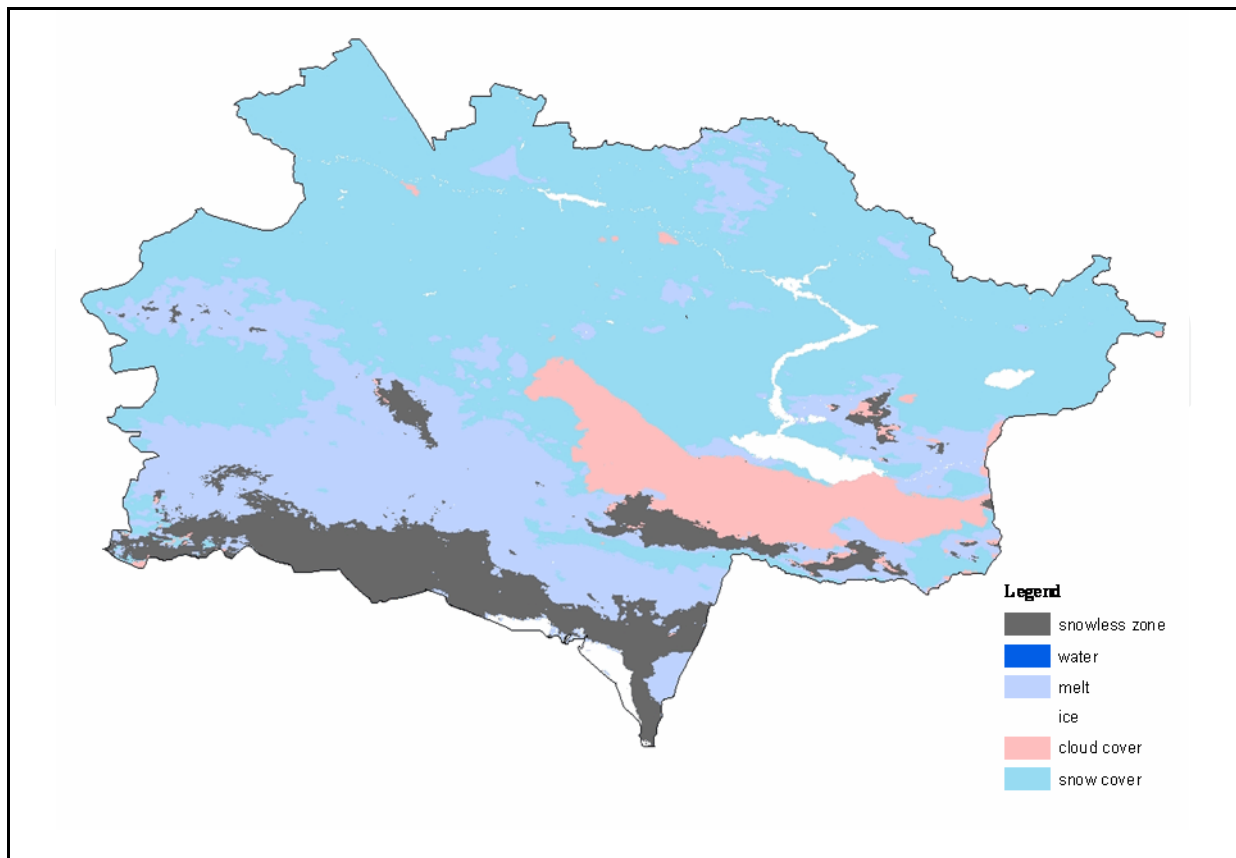


Fig. 2. Daily map of snow coverage (East-Kazakhstan oblast, March 22, 2009)

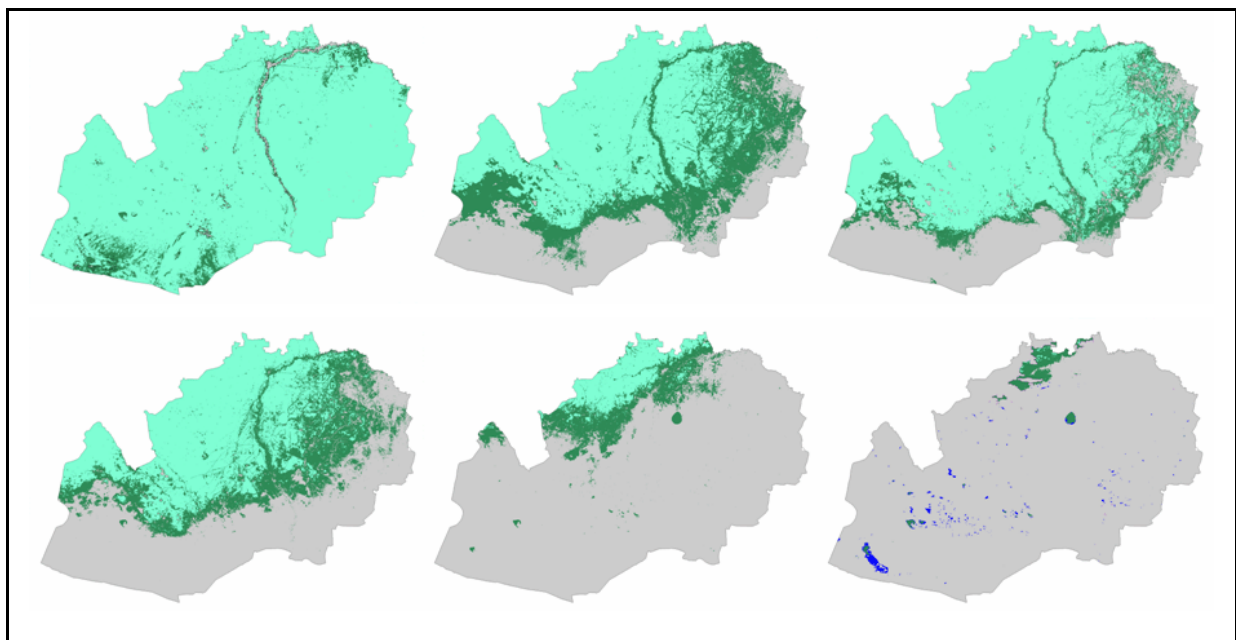


Fig. 3. Decade maps of snow melting (Western-Kazakhstan oblast)

Monitoring of destruction of the ice cover on large water objects (Balkhash, Alakol, Buhtarma, etc.), represents certain interest for regional emergency agencies. Figure 4 shows

the dynamics of destruction of the ice cover on Lake Balkhash in March, 2007. The figure also shows zones of active thawing.

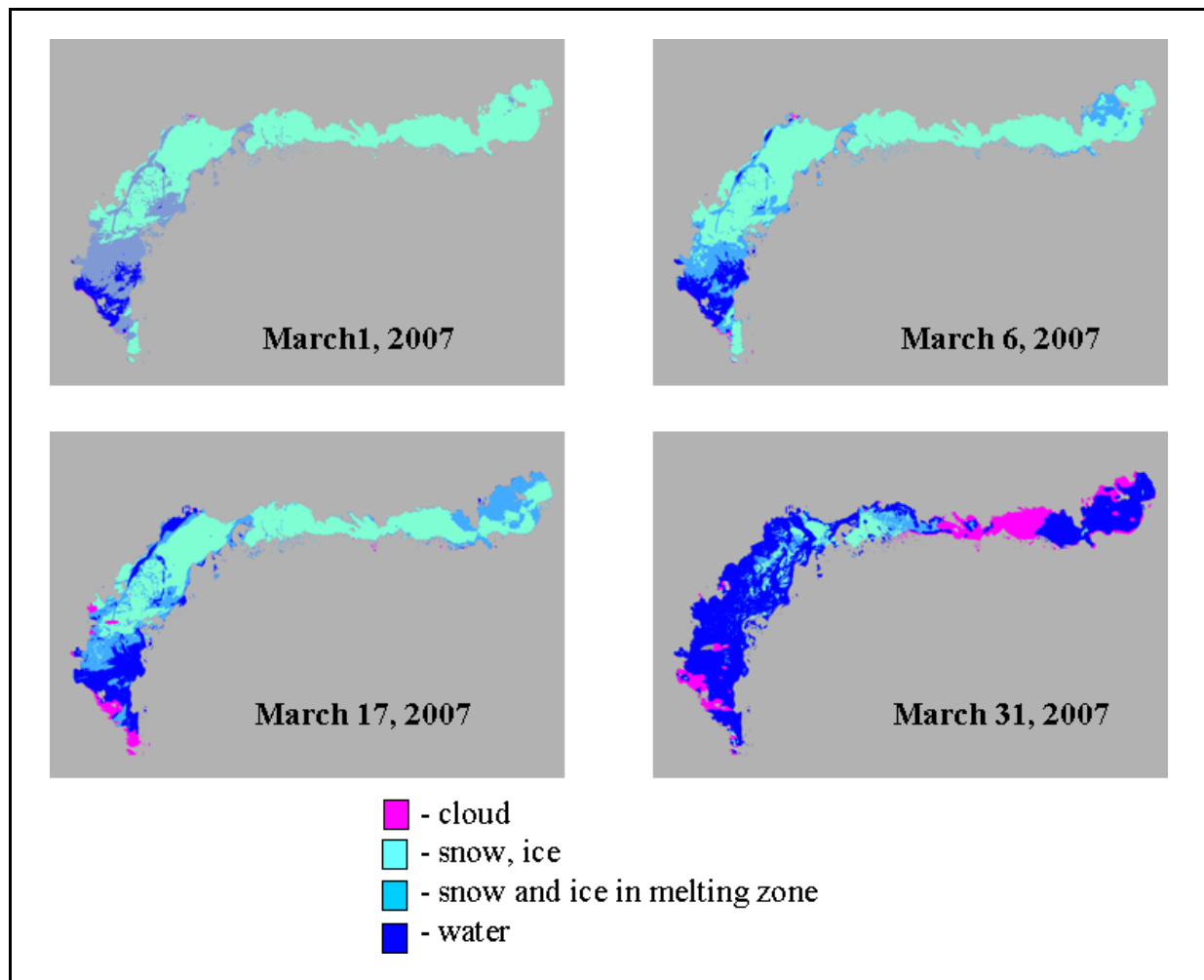


Fig. 4. Dynamic of ice destruction in Balkhash Lake in 2007

5. System of operative flood space monitoring

5.1 Space segment

Functional basis of work of flood space monitoring system in an operative mode are the reception stations of remote sensing data located in Astana and Almaty. They carry out regular receiving of data from NOAA, EOS Terra and Aqua, Indian satellites IRS and Canadian radar satellite RADARSAT-1. Zones of radio visibility of receiving stations cover Kazakhstan, a significant part of Russia and Asian region.

5.2 Technology of flood space monitoring

The technology of flood space monitoring /figure 5/ is based on daily EOS-AM Terra MODIS images of territories for which there is a high risk of flooding, including the parts located in the neighbor countries. The main task is operating mapping of flooding zones during floodwater passage. On the basis of these images after thematic processing, masks of

flood areas are created. Zones of flooding are defined as a difference of water surfaces in normal conditions and during high water. To except cloudy cover and clouds shadows the cloud mask is used. To except wet soil the vegetation index NDVI is used. The operative situation is compared to maps for the previous day and the most dangerous territories with high dynamics of developing of increase water are identified.

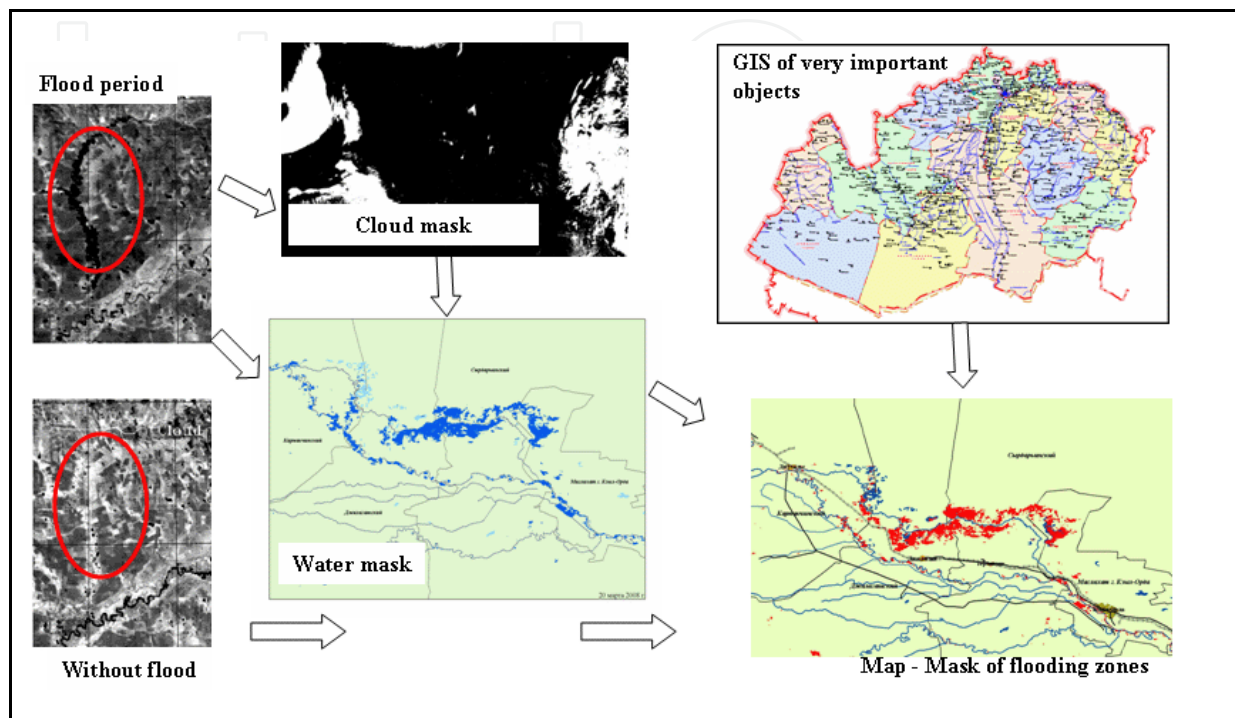


Fig. 5. Functional scheme of the GIS-technology of operative flood space monitoring

In order to estimate the potential danger of flooding special GIS is used. It contains the information about settlements and towns, road and railway networks, lines of the electric system, oil-and gas pipelines, forests, especially important objects, etc. Combining these layers and zones of flooding it is possible to define their location with respect to the nearest settlements and especially important objects, and distance up to them. Final maps of flooding zones /figure 6/ are sent by e-mail to regional emergency agencies.

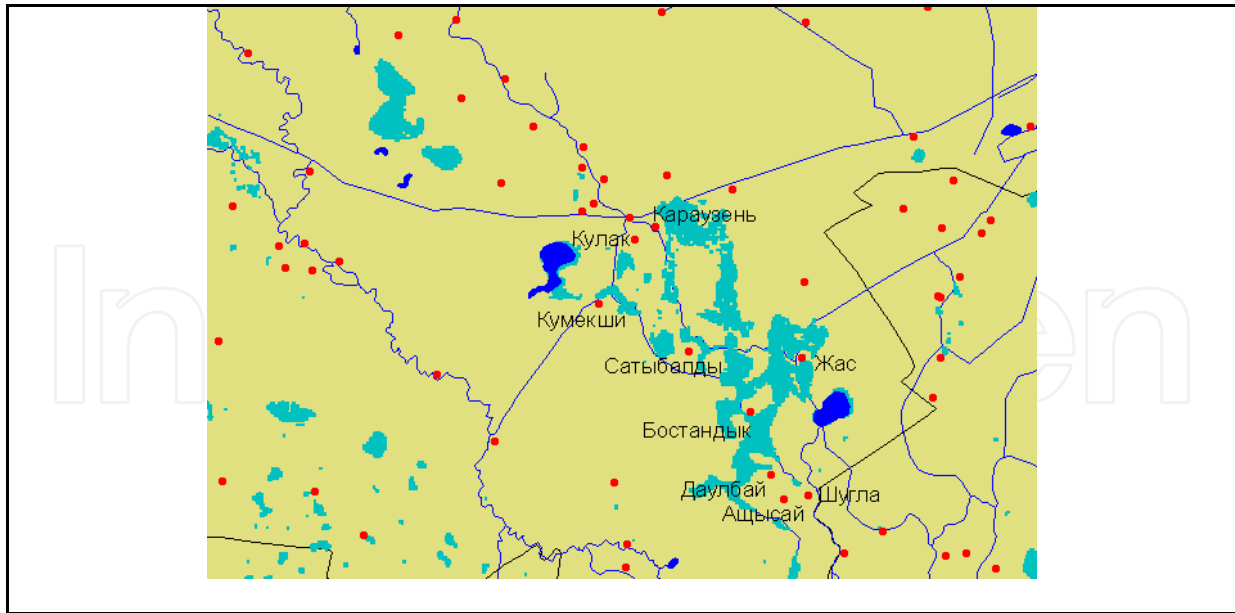


Fig. 6. Map of flood zones on the territory of Kaztalovsky raion of West-Kazakhstan oblast in April 8, 2004

5.3 Algorithm of allocation of flooding zones on space images

The problem of allocation of flooding zones on remote sensing data is solved using the algorithms of automatic classification in the programming environment ArcGIS-9.1 passes in three stages /figure 7/. At the first stage five basic classes of objects are allocated: a cloudy cover, a snow cover, a water surface covered with ice, a water surface and a terrestrial surface free from snow.

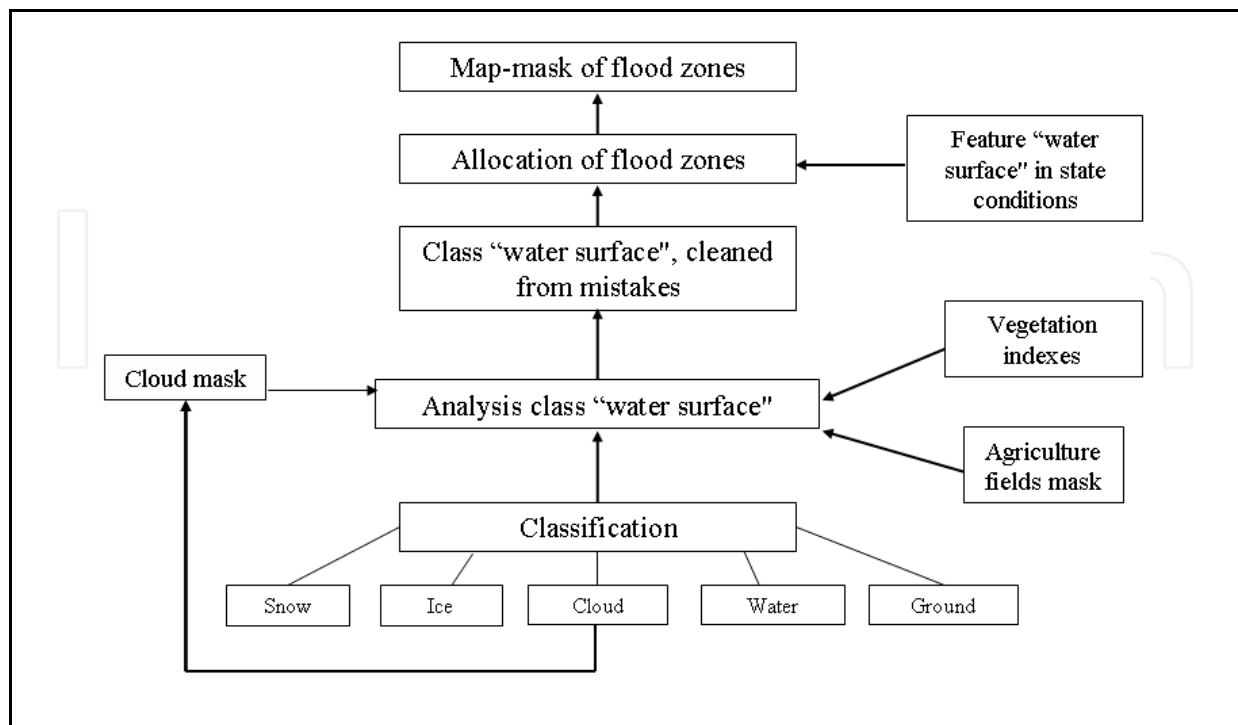


Fig. 7. Algorithm of allocation of flood zones on space images

The main interest is presented by a water surface. Therefore at the second stage the additional analysis of this class for the purpose of allocation of false objects is carried out. First of all, it is shades from clouds, lately ploughed fallows and wet soils. In order to except the cloud mask received at the first stage, and fact that shades on a configuration repeat clouds are used. In order to remove fallows which are false carried to water objects, masks of agricultural fields and analysis of their structure are used. Wet soils are excluded by means of analysis using vegetation indexes /figure 8/. Let's notice that sometimes sunlight dazzles from a water surface creating additional hindrances. Besides it is necessary to know the normal state of water objects in order to indicate deflections in their location.

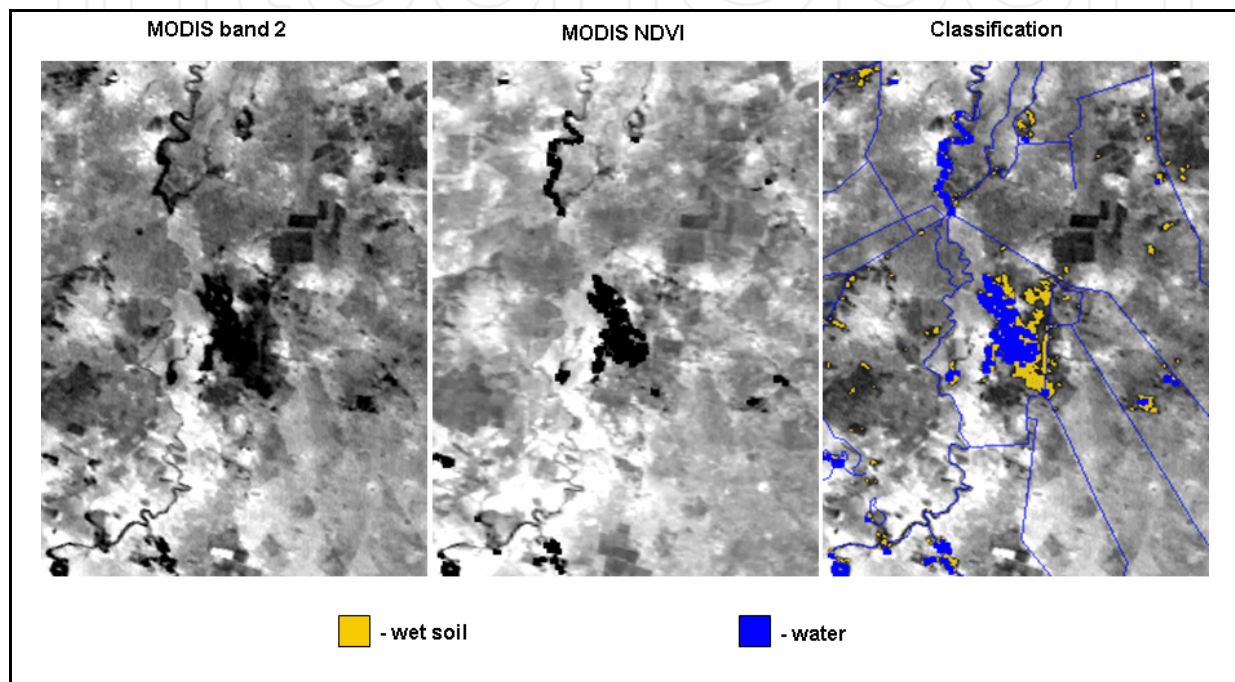


Fig. 8. Classification of water surfaces and wet soil by MODIS data

At the third stage operative maps of the flooded territories /figure 6/ at level of region and separate districts are formed using the mask of water surfaces in the normal conditions defined on the autumn space images.

6. Estimation of flood risk zones

First of all, it is necessary to note that concept «the estimation of risk of an emergency situation (fires, flooding, etc.) » has dual sense. On the one hand, it is a current estimation of a real condition of concrete territory during a concrete period of time which is formed by the characteristics of this territory (a relief, vegetation etc.) and its meteorological condition (temperature, amount of precipitation, their intensity, storm activity, etc.) during a concrete period of time. On the other hand, «the estimation of risk of an emergency situation» can be formed on the basis of a statistical estimation of results of long-term supervision of investigated territory, including the remote sensing data. Such approach allows to receive an integrated estimation at any time period in each concrete place. In this case it is not required to know the characteristic of the land environment. We follow the second method of estimation.

In process of accumulation of the information time series remote sensing data (seasonal and long-term) are formed. They enable to characterize the development of flood situations in time during a current season and to compare them with the previous seasons. Also on the basis of analysis of all long-term series of remote sensing data we can estimate risks of flood situations on various territories. The territories are ranged by the degree of risk of flooding by freshet waters and floodwater. For this purpose available long-term series of remote sensing data are analyzed and the frequency of territory flooding is defined. The more often the territory flooded in this period, the higher is the risk of flooding.

The functional scheme of GIS-technology of zoning of investigated territory by the degree of flood risk using the long-term space monitoring data consists of three blocks corresponding to three stages of determination of resultant estimation in the programming environment ArcGIS-9.1 /figure 9/. The first is formed by the daily data about the areas which have suffered from flood (flooding zone), received in the process of operative monitoring. The second contains the annual data about the total areas which have suffered from flood which are formed of the data of the first block and represent total zones of flooding for each concrete year. The third block contains results of zoning of investigated territory by the degree of risk of flooding which are calculated from the analysis of the annual data.

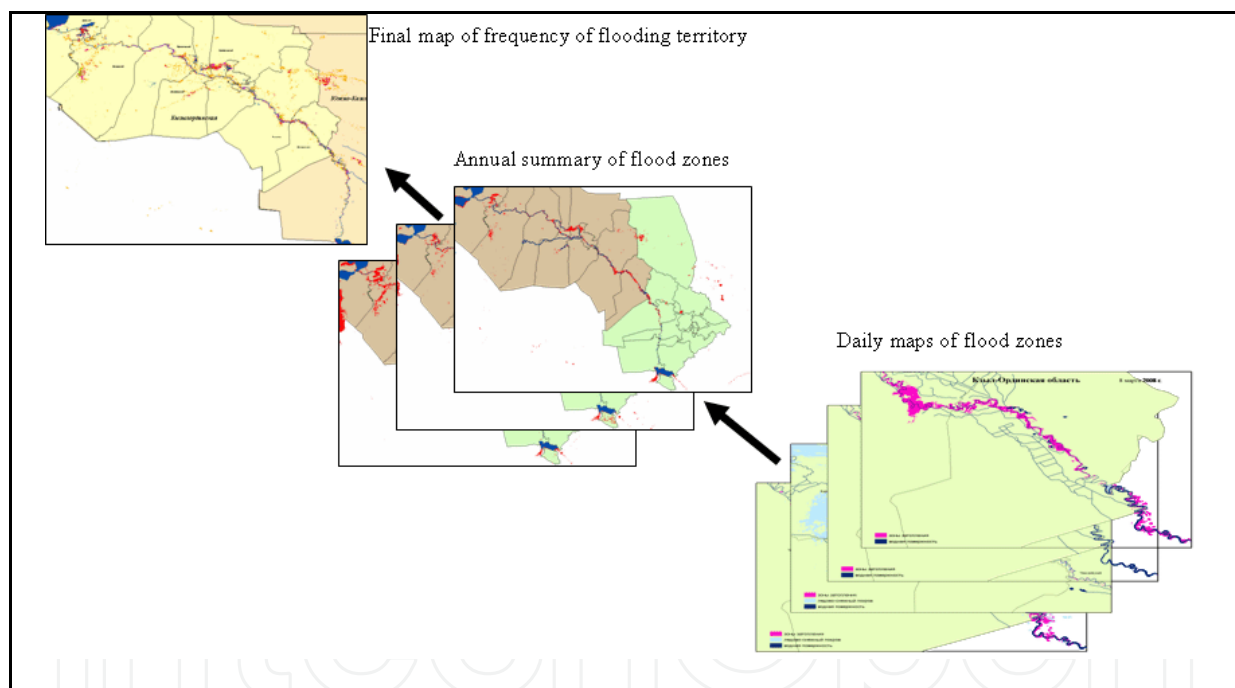


Fig. 9. Functional scheme of technology of estimation of flood risk zones

Such information is very useful for planning economic activities. Besides it is useful for planning protective actions against repeated emergency situations and for analyzing the efficiency of the measures accepted by local authorities for struggle against high waters. Not all zones of flooding present danger to life and the human economic activities. Some of them can be even useful. For example, places of gathering of freshet waters which are used by nature and man in the further.

7. Practical results of flood space monitoring

Flood space monitoring is exploited in West-Kazakhstan (2003-2009), Karaganda (2005-2009), East--Kazakhstan (2007-2009) oblasts and Syrdaria river region including a Chardara water basin (2003-2009) in real or near real time mode. Space monitoring of high waters is carried out in the spring, basically in March - April, and for a middle stream of Syrdarya during the winter-spring period. For all observable regions, except Syrdarya, in the recent years (2006-2009) weak high waters are observed. In the middle stream of Syrdarya there are critical situations every year. Also in 2009 there was a flooding of some settlements located around one of the lakes in East Kazakhstan which was caused by climatic features of the past years. Earlier these places were not flood. Some results of flood space monitoring are described described further.

7.1 Space flood monitoring of West Kazakhstan

In this region there are the Ural River and many small rivers running and not running into the Ural. Local agencies of emergency situations have defined the most important objects for space monitoring in a high water period /figure 10/. This group also included the objects located in territory of Russia which in many respects define passage of flood waters on the Ural River.

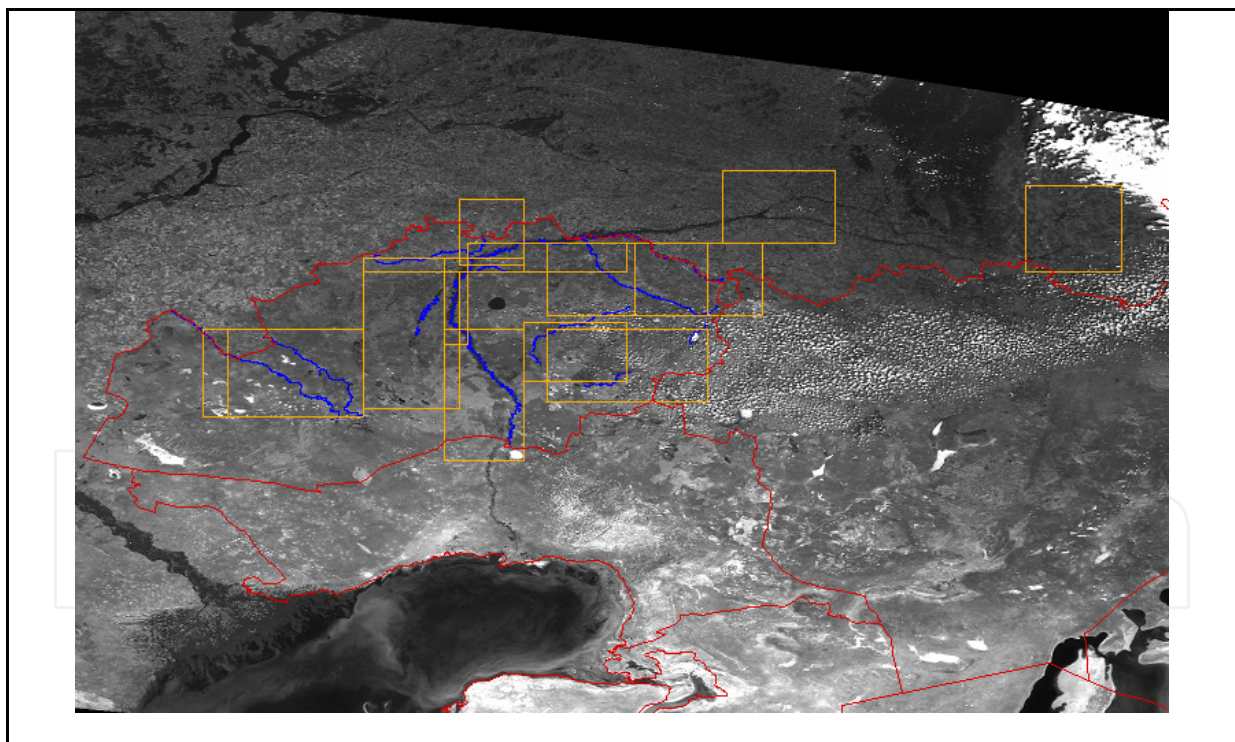


Fig. 10. Most important regions in flood period on the territory of West-Kazakhstan oblast and Russia

The results of long-term monitoring show that more or less intensive high water was observed in first three years. In 2003 the high water has begun in the second decade of April, reached its peak in the middle of April and practically vanished at the beginning of May. Thus the water level in the river Ural Mountains was below the average, and in a number of

small rivers above the average (in some areas it was strong). In 2004 the water level was below the average practically everywhere. In 2005 the high water appeared early (at the beginning of April) and continued to increase till the middle of May, then it began to decrease, but at the beginning of June it did not vanish. Thus the basic water stream passed on the Ural River. Further intensity of high waters has considerably decreased.

It is necessary to note, that high overcast is a vital problem for carrying out of operative space monitoring of flooding, especially in the West Kazakhstan. So in 2005 during 45 days of high water development we managed to receive 16 space images of territories of West Kazakhstan, suitable for mapping of flooding zones. For separate areas this value was even less. For example, for the Uralsk area we got 9 images. In 2007 during the high water development it was not possible to receive any space images of this territory, suitable for mapping of flooding zones. In 2008 and 2009 the situation was better, only there was no high water.

In the West Kazakhstan often happens that at night the overcast is lower than during the daytime. Therefore the night images NOAA AVHRR and EOS-AM Terra MODIS in infra-red band are used for flooding monitoring /figure 11/. The water has higher thermal lag, therefore water surfaces at night are warmer than ground (soil). In the paper (Barton & Bathols, 1989) it is noticed that sometimes during the flood the thermal canals at night gave better land-flood discrimination than the visible data during the daytime. Certainly radical way of solving the a problem of overcast is monitoring of only areas with especially dangerous freshet situation of data RADARSAT, but it is limited due to their high cost and complexity of the operative order.

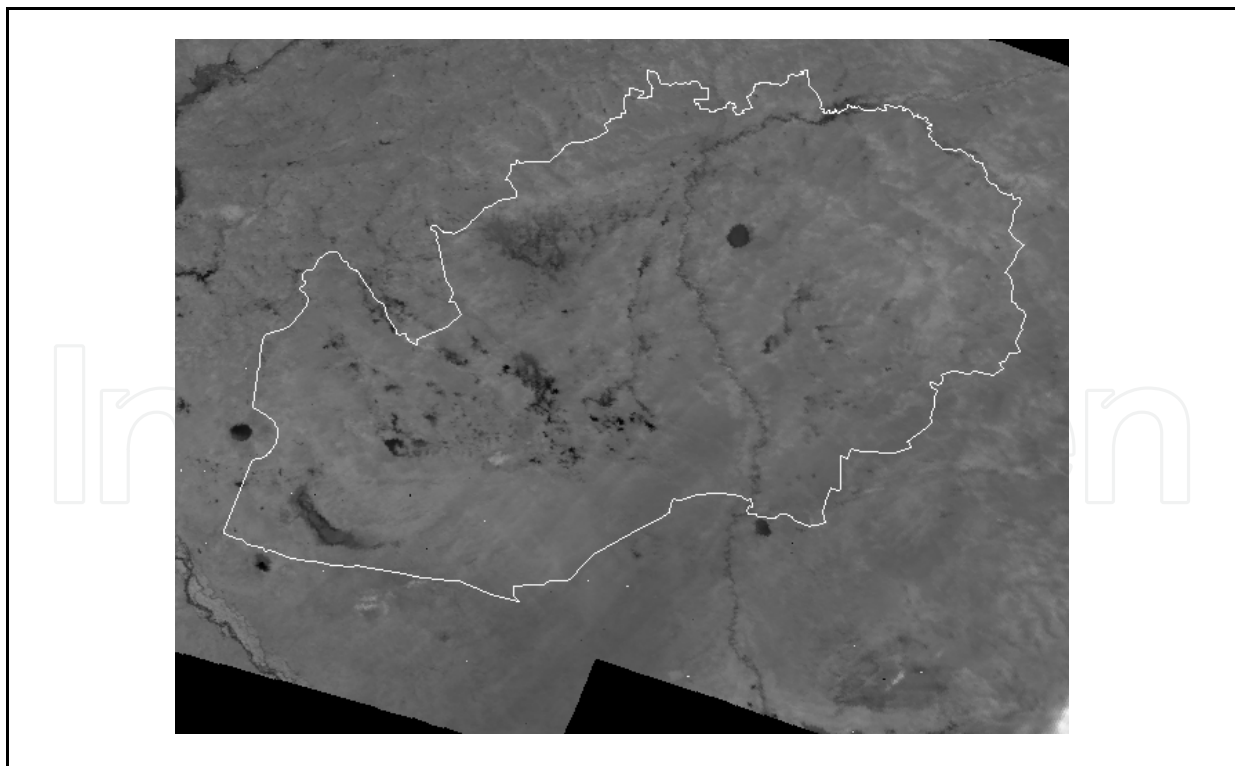


Fig. 11. Night image NOAA AVHRR (West-Kazakhstan, 28 April 2003)

7.2 Space Monitoring of Syrdaria Region

Last six years in this region the intense situation with flooding is observed. As is has been noticed above, the reason of it is not settled question of use of the river water between Kazakhstan, Uzbekistan and Kyrgyz Republic. In the Soviet period the Togtogul water basin in the Kyrgyz Republic, situated in riverheads, was used mainly for the agricultural purposes. In the winter it accumulated water, and in the summer water went down for watering of agricultural fields, mainly cotton. Now the Kyrgyz Republic actively uses this water basin for electric power generation, especially in winter. As a result, there is active discharge of water in winter. Surplus of water arrives at the Chardara water basin located downstream. It is located on border of Kazakhstan and Uzbekistan. For prevention of danger of overflow of a water basin during the spring high water the Kazakhstan authorities are forced to dump part of water downstream. It leads to flooding of territories in middle stream of Syrdaria river.

For the first time such situation arose during the winter of 2003-2004. During the winter of 2004-2005 a real danger of overflow of the Chardara reservoir was created. The government of Kazakhstan hardly managed to convince Uzbekistan to open dump of water in Arnasai hollow and stabilize the situation. In 2004-2005 the conditions turned out to be even more difficult. The winter of 2003-2004 was not snowy with very early spring. Precipitations were heavy in the winter of 2004-2005, they were much higher than the norm. Heavy snowfalls created snow stocks in the mountains. Besides, strong frosts held down a thick layer of ice on the shoaled river-bed of the Syrdaria. Late spring shifted terms of active high water (melting of snow). Therefore the most dangerous situation developed in the middle of March.

The situation on the Chardara water basin is one of the main characteristics of the freshet situation. Therefore from the end of 2003 the remote sensing control of filling of Chardara reservoir and development of high waters over this region in the real time mode has been carried out. Figure 12 shows dynamics of changes of the Chardara reservoir water surface in 2003-2008. As follows from figure 12 the situation was difficult almost every season. However, if during first two seasons the authorities were afraid threat of overflowing of the water basin, further the situation was under the control of regional authorities, except two critical situations in 2007 and 2008.

In 2007 the critical situation arose at the end of the first decade of February and led to flooding of the populated territories in area of Kzyl-Orda (figure 13). For find out of the reasons of this process we gave the regional authorities the information about the dynamics of filling of the Chardara reservoir during this period. From figure 13 shows that, firstly, at this time there was a discharge of water from the Chardara reservoir (left diagram), and, secondly, it was filled by two thirds of the maximal size, which was fixed during many years supervision (right diagram). Whether it was the reason of the critical situation, we could not prove. The special commission found out this reason.

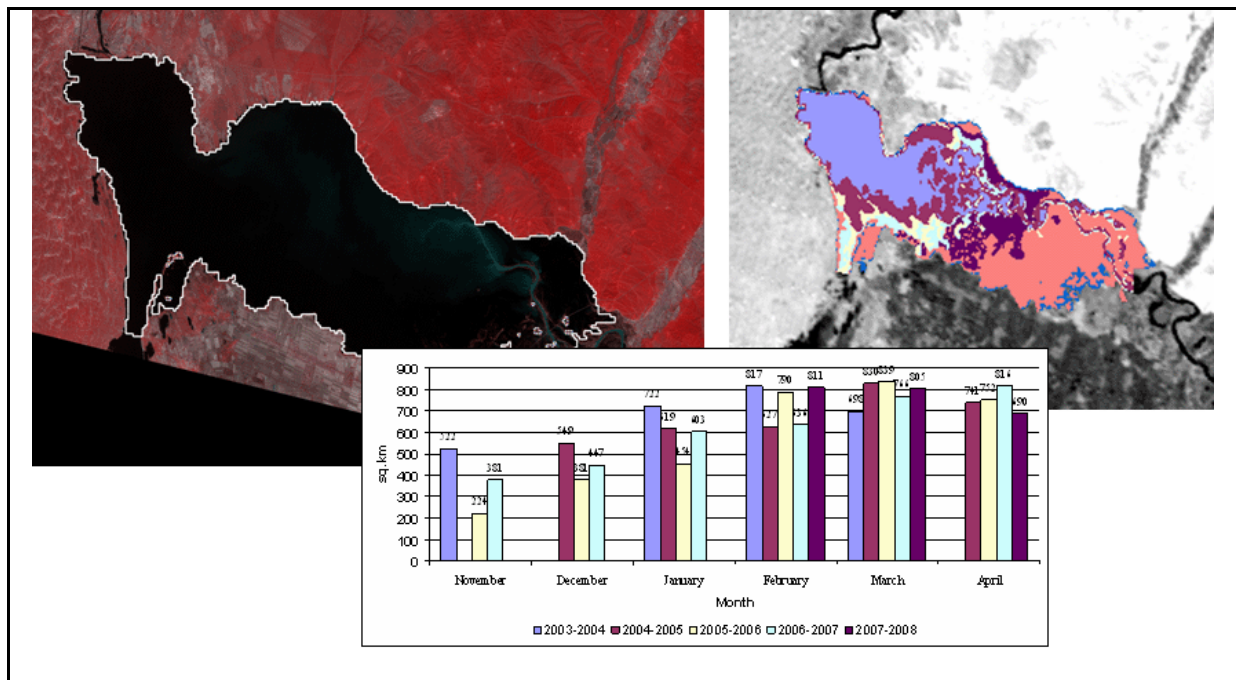


Fig. 12. Analysis of Chardara filling dynamic from 2003 to 2008

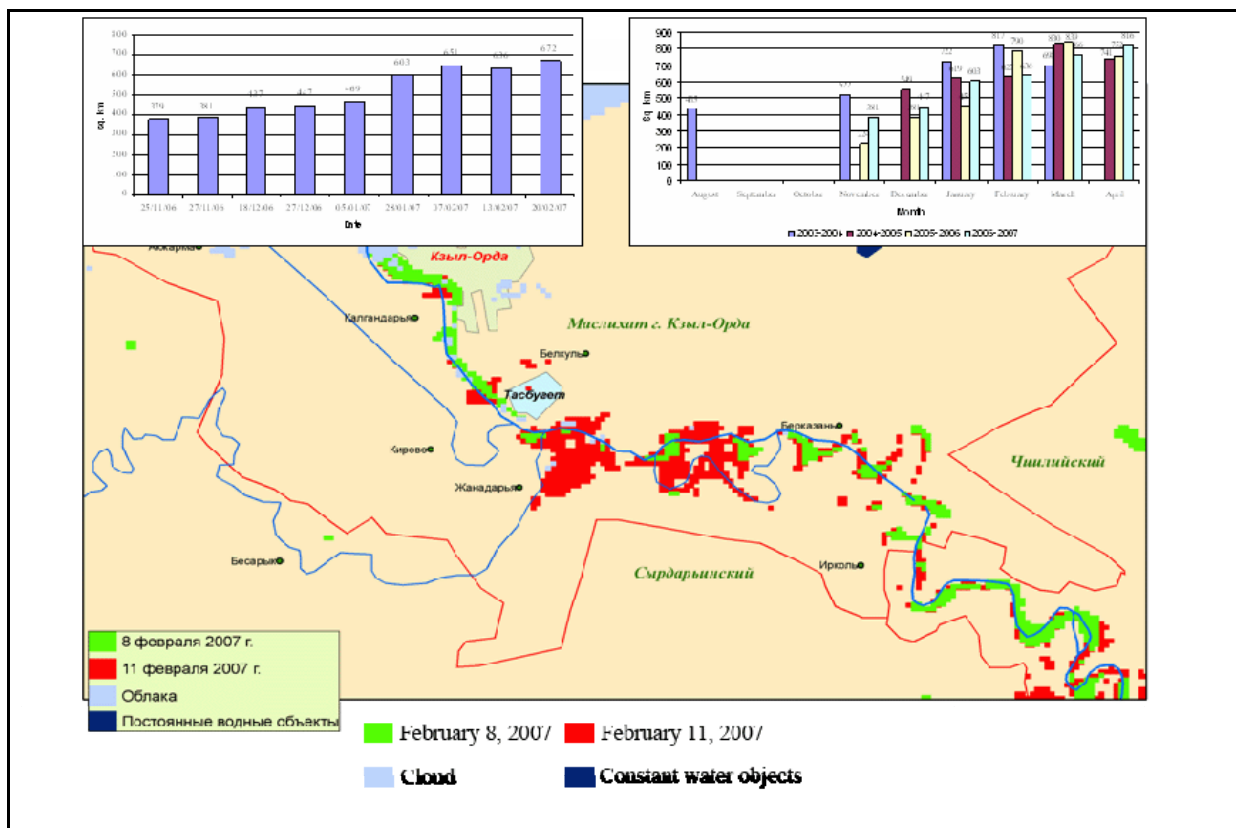


Fig. 13. The analysis of the reasons of break of a dam near Kzyl-Orda in first decade of February 2007.

Flooding in the third decade of February 2008 had much more serious consequences both in terms of the number of flood victims and destroyed houses. The reason of it was not the

Syrdaria. The reasons were storm rains abnormal for this period of the year and abnormal cold winter which turned the ground into an ice trench. The settlements which had never been flooded and were not ready to such situation suffered from flooding. Actually, high water on the Syrdaria passed without special problems (figure 14). We could not fix the critical situation during the peak period with the help of MODIS data because of the overcast, and used for these purposes RADARSAT data, which did not help either because of some objective and subjective reasons, in particular, because of impossibility of the operative order.

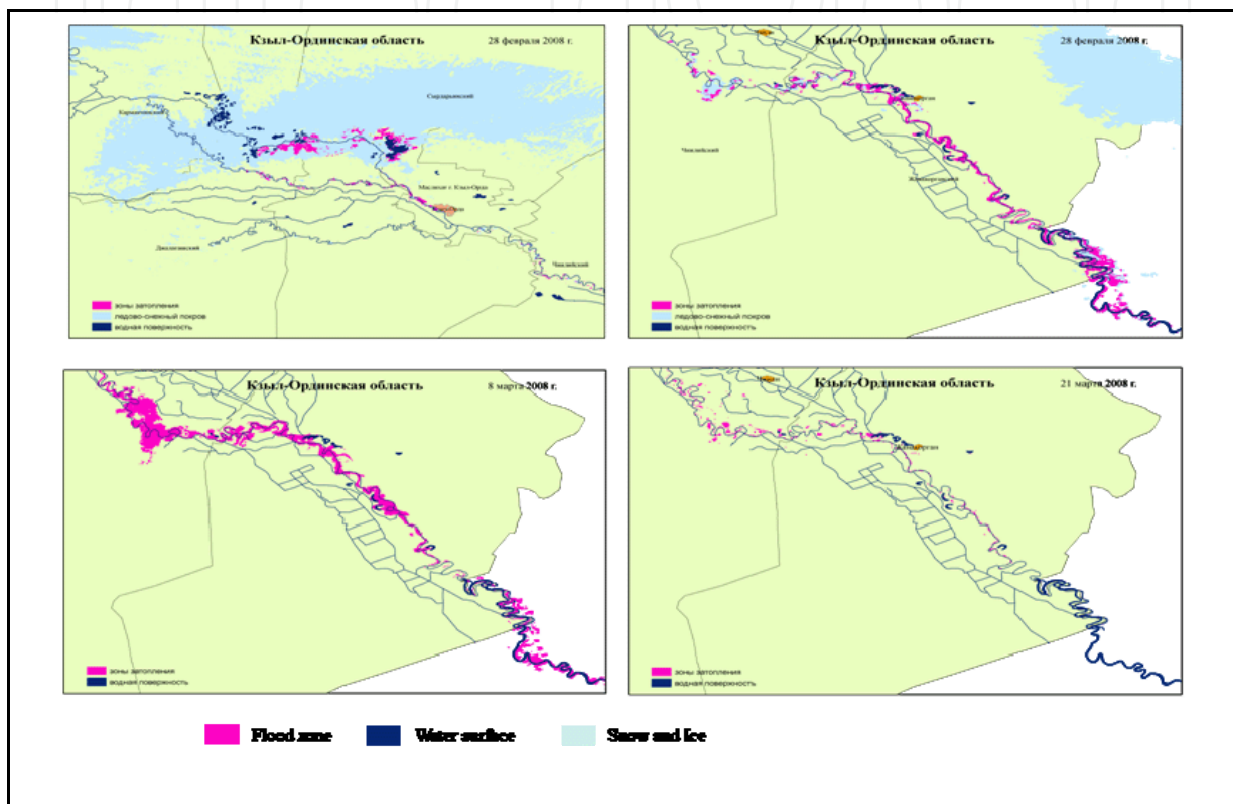


Fig. 14. Development of flood situation in the middle stream of Syrdaria river in spring 2008 (North part of Kzil-Orda oblast, 28 February; South part of Kzil-Orda oblast, 28 February; South part of Kzil-Orda oblast, 8 March; South part of Kzil-Orda oblast, 31 March)

Let's notice that same critical situation has arisen this year in East Kazakhstan (look above the text in paragraph 7 beginning).

In 2009 the high water has passed easy in the middle stream of Syrdaria river.

7.3 Zoning on degree of risk of flooding of territory of the West-Kazakhstan and a middle stream of Syrdaria River

The technology of estimation of flood risk zones described above has been used for zoning by the degree of risk of flooding of the territory West Kazakhstan (a six-year number of the remote sensing data is analyzed), and middle stream of the Syrdaria River (high waters for the last five winter-spring periods are considered).

Figure 15 maps of zones of risk of flooding on the territory of West-Kazakhstan oblast, as a whole and its separate fragments. For these years more or less intensive high water was

observed on the territory only two times, but the same information allows to carry out analysis of danger of high waters for various territories.

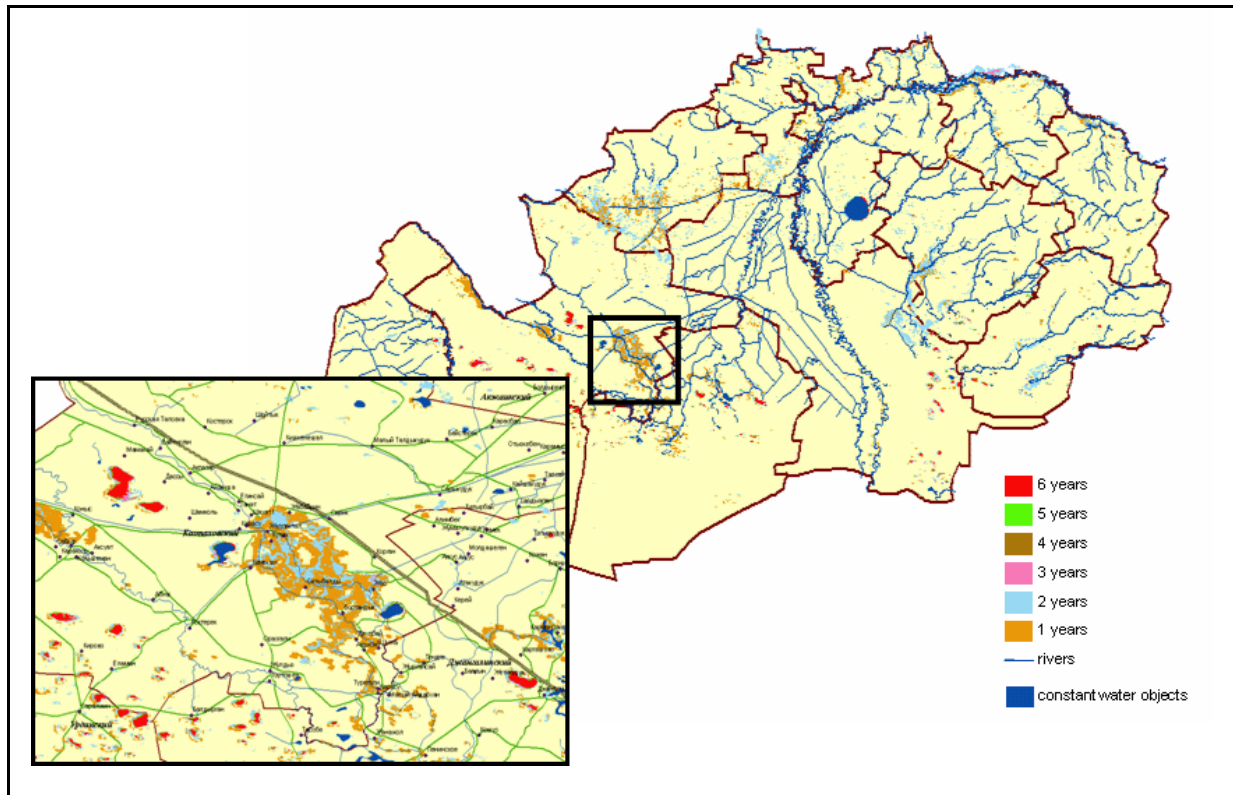


Fig. 15. Zoning territory of West-Kazakhstan oblast by the risk of flooding for 2003-2008

From the insert of figure 15 we can see that territories constantly flooded during 6 years are located far from settlements and roads. They do not represent danger and are regular places of gathering of flood waters as are located far from constant water objects. On the other hand the territories flooded only one or two times, are located in immediate proximity from settlements and roads. It is necessary to pay paramount attention to these territories in planning of protective actions.

More difficult situation was with high waters in the middle stream of Syrdaria River where practically every year there were critical situations. The results of zoning of the territory in the middle and the low stream of the Syrdaria River (Kazakhstan part of the river) by the degree of risk of flooding for the last five winter-spring periods are presented in Figure 16. In more details these results are presented in the insert of figure 16 for one of the main flooded territories in the middle stream of Syrdaria River. Figure 17 shows the same territory with spatial allocation of zones with high frequency of flooding (3-5 times for 5 seasons) is presented. Especially critical situation developed for settlement Dzhusaly where regularly flooded territories are located in immediate proximity from it and on the territory, where the railway is located.

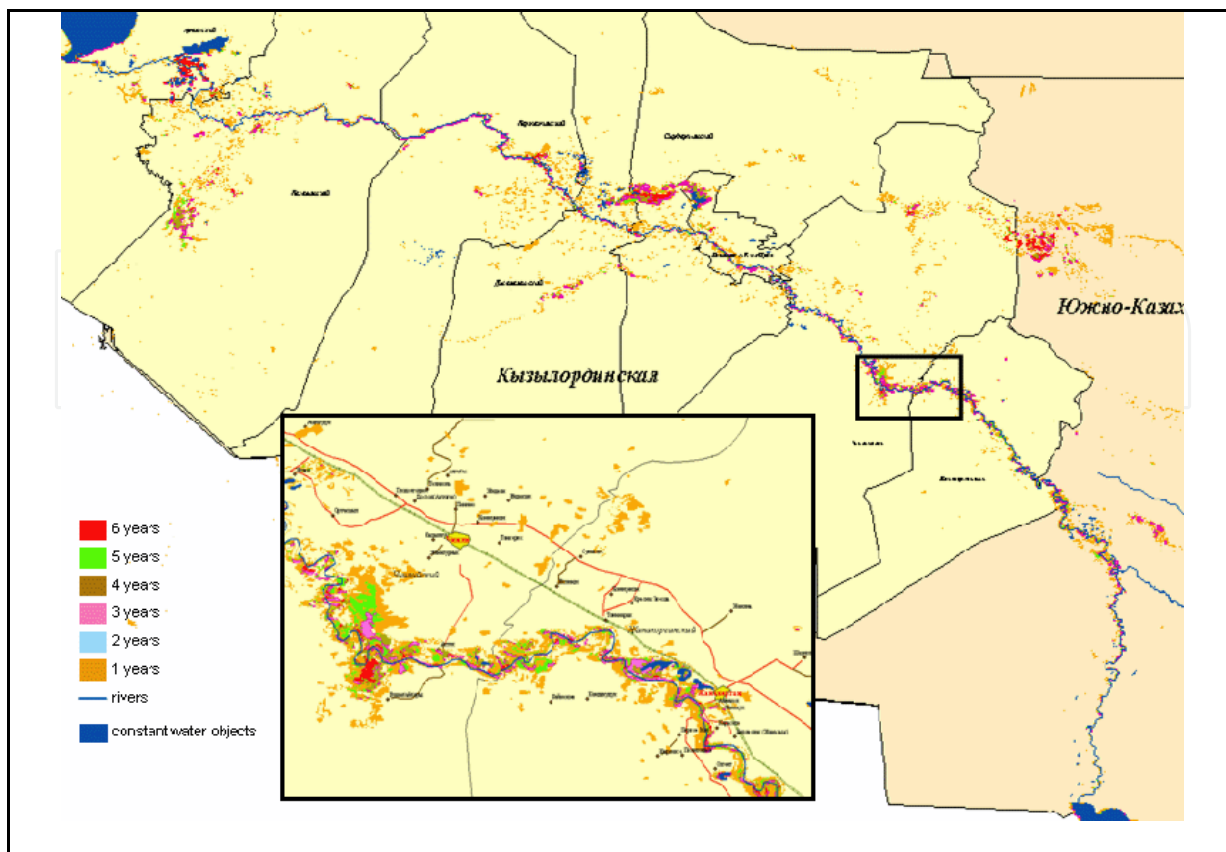


Fig. 16. Zoning territory in the middle part of Syrdaria river by the risk of flooding for winter-spring period of 2003-2008

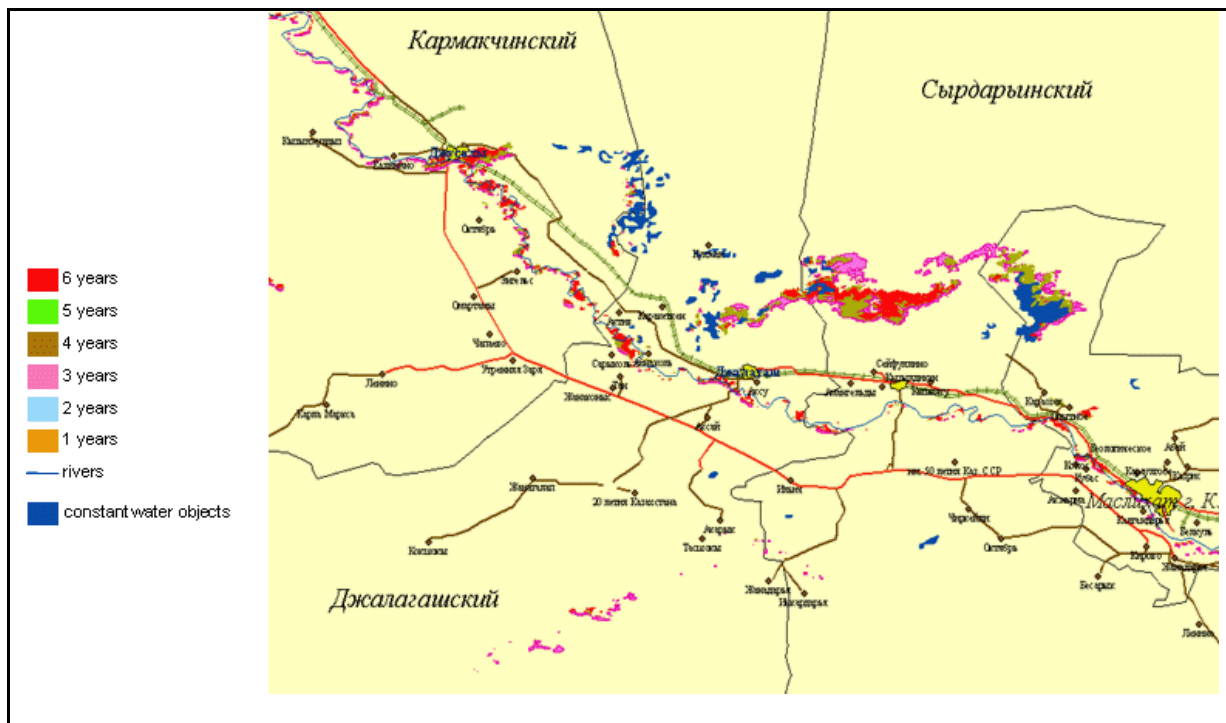


Fig. 17. Zoning territory in the middle part of Syrdaria river by the high risk of flooding for 2003-2008

7.4 Space monitoring of pollutions of a surface of a water basin

In the first decade of October 2008 on the water surface of the Shulbinsky water basin the green color pollutions, well identified in space images, were detected (figure 18). Pollution was observed on 5, 6 and 8 of October. At first, it was supposed that it is industrial pollution as drinking of the infected water led to cattle poisoning. As a result of analysis of space and ground-based data the agency of emergency situations came to a conclusion that the pollution was caused by vegetative objects (seaweed).

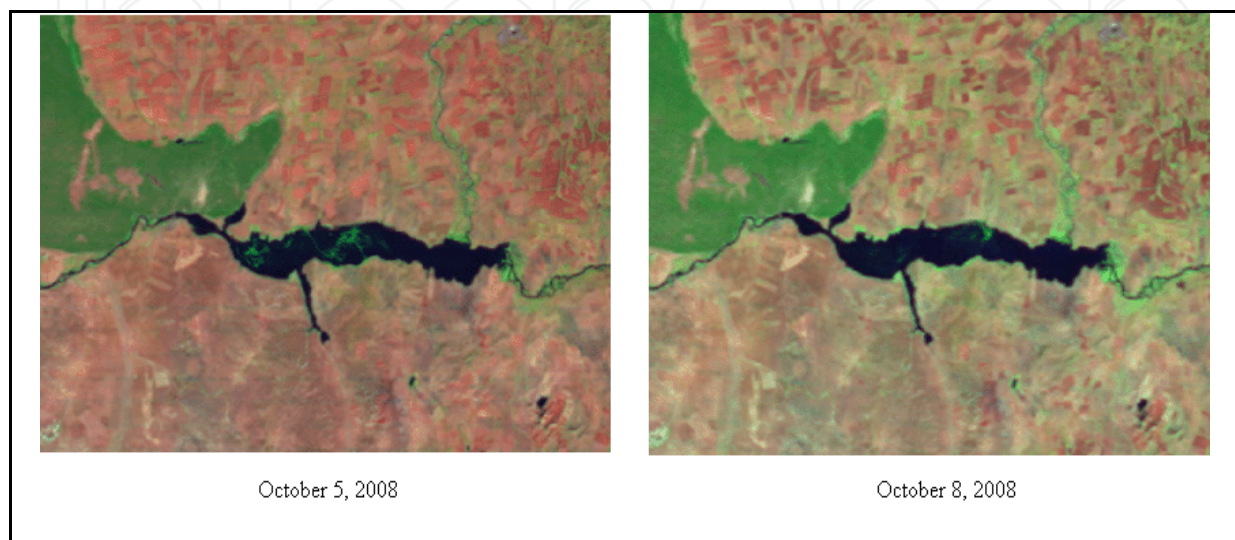


Fig. 18. Mapping of pollution on the surface of Shulbinsky reservoir (East-Kazakhstan oblast)

8. Modeling

Recently emergency departments have shown interest to modeling of various extreme situations on water objects. It is modeling of zones of flooding as a result of flooding, high waters or break of dams; modeling of deformations of river-beds; and modeling of protective constructions. The solutions of these tasks are based on the software packages (BOR, RIVER, FLOOD) developed in Institute of Power Constructions (Russia) by Belikov V.V.

9. Conclusion

Application of the results of space monitoring of flooding in practical work of emergency agencies will enable to lower the damage due to early detection of freshet floods and realization of preventive measures decreasing the danger of flooding in zones of high risk of their occurrence, detected on the long-term remote sensing data.

Nowadays application of the results of space monitoring of passage of freshet waters and flooding has basically information character. One of mainstreams of development of flood space monitoring in Kazakhstan is search of optimum variants of use of high-resolution data resolution, including radar. In this case the efficiency of monitoring considerably increases. At present wide application of such data for operative space monitoring of high waters and flooding is limited by their high cost and complexities of the operative order.

The other direction of development of technologies of space monitoring of water objects in interests of regional emergency departments is use remote sensing data for modeling of potential extreme situations (flood, break of dams, washout of coast, etc.).

The results of territory zoning by the degree of risk of flooding can be useful for planning of economic activities: building of industrial enterprises, main gas pipelines, electric mains, etc. They can also be used for solving of some other problems. In particular, they are useful in planning of protective actions against repeated flooding, and in analyzing efficiency of measures taken by local authorities in struggle against them. Another possible application can be use of these data by insurance agencies.

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Our planet is nowadays continuously monitored by powerful remote sensors operating in wide portions of the electromagnetic spectrum. Our capability of acquiring detailed information on the environment has been revolutionized by revealing its inner structure, morphology and dynamical changes. The way we now observe and study the evolution of the Earth's status has even radically influenced our perception and conception of the world we live in. The aim of this book is to bring together contributions from experts to present new research results and prospects of the future developments in the area of geosciences and remote sensing; emerging research directions are discussed. The volume consists of twenty-six chapters, encompassing both theoretical aspects and application-oriented studies. An unfolding perspective on various current trends in this extremely rich area is offered. The book chapters can be categorized along different perspectives, among others, use of active or passive sensors, employed technologies and configurations, considered scenario on the Earth, scientific research area involved in the studies.

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